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Zhou

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(54) **METHOD AND APPARATUS FOR HERMETICALLY SEALING PHOTONIC DEVICES**

(75) Inventor: **Ping Zhou**, Glendale, AZ (US)

(73) Assignee: **Finisar Corporation**, Sunnyvale, CA (US)

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(51) **Int. Cl.**[7] **G02B 6/36**
(52) **U.S. Cl.** **385/94**; 385/88; 385/92
(58) **Field of Search** 356/94, 88, 92; 257/779, 787, 790

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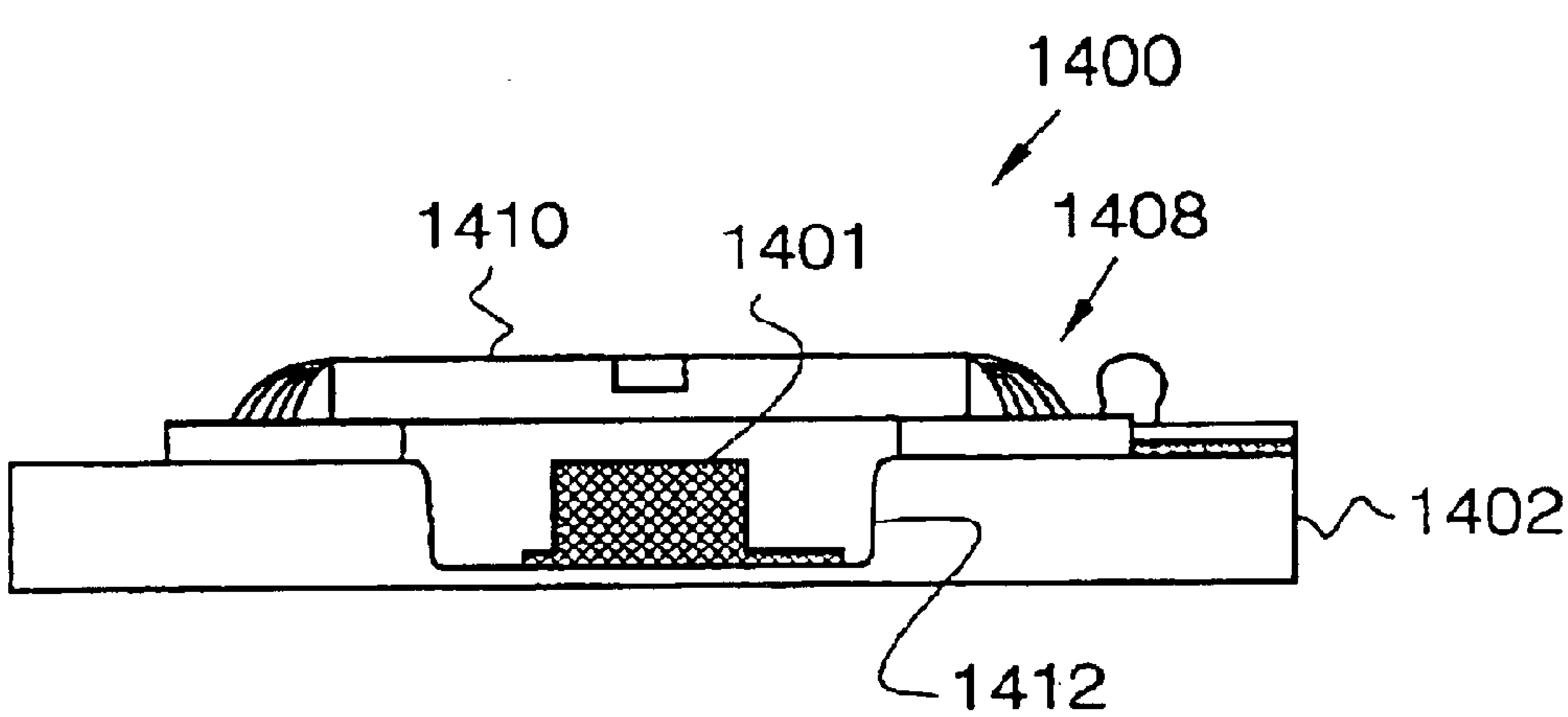
Primary Examiner—Gregory J. Toatley, Jr.
Assistant Examiner—Roy M. Punnoose
(74) *Attorney, Agent, or Firm*—Workman Nydegger

(57) **ABSTRACT**

A hermetically sealed photonic device submount includes a photonic device mounted on a substrate material and sealed in a flexible hermetic seal. In one configuration, the photonic device is configured to emit or to receive light through the substrate material. In this configuration, the photonic device is covered with an adhesive layer and a metal layer deposited onto the adhesive layer. In another configuration, the photonic device is configured to emit or to receive light in a direction substantially vertically upward from the substrate material. In this configuration, a cover is placed over the photonic device, then the cover is hermetically sealed to the substrate material with an adhesive layer and a metal layer depositd onto the adhesive layer. In both configurations, the photonic device submounts are hermetically sealed according to various aspects of the present invention on the substrate material without using a separate package. Accordingly, any number of hermetically sealed photonic device submounts can be mass produced on wafers using the present invention.

14 Claims, 9 Drawing Sheets



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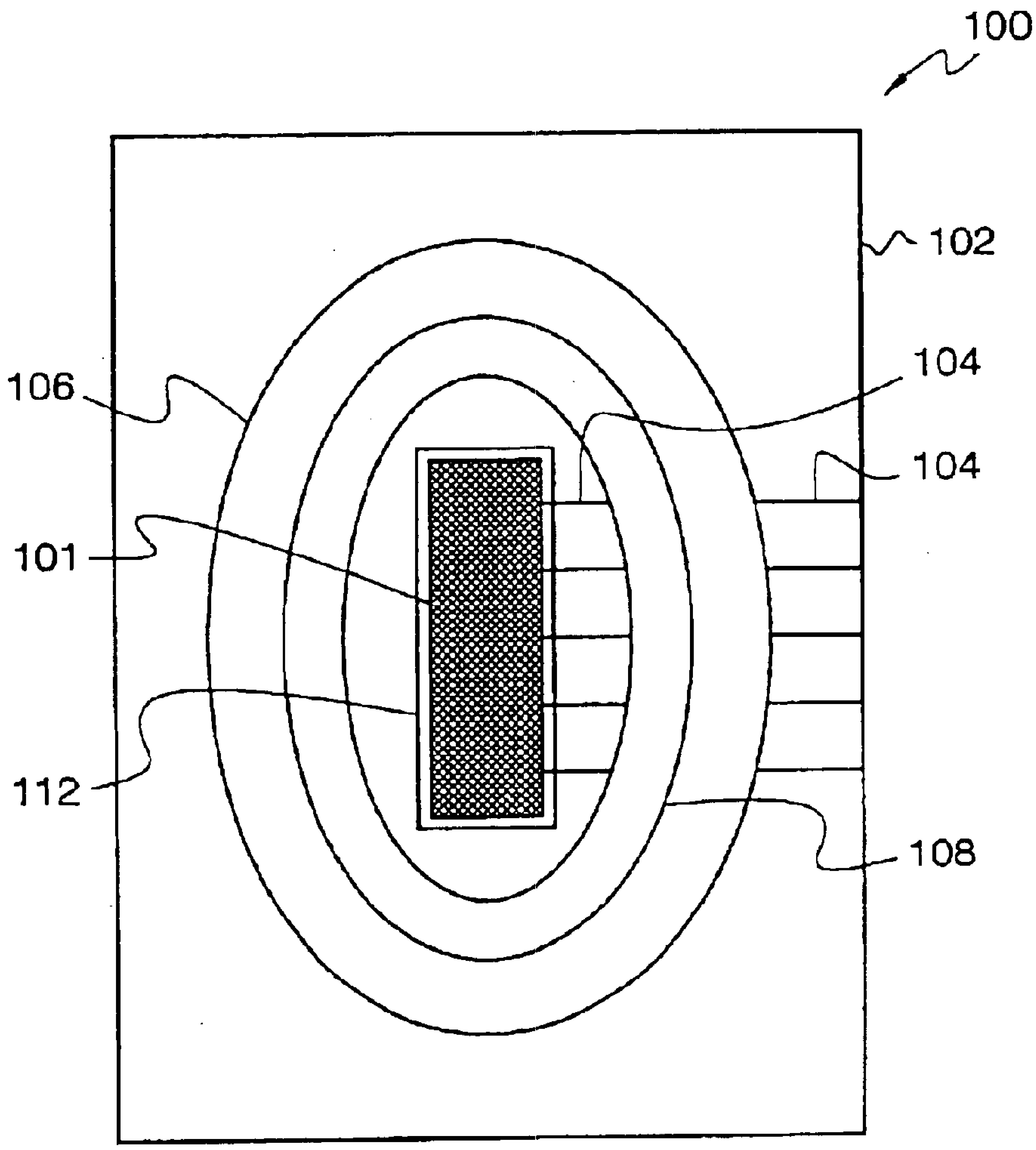
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Fig. 1

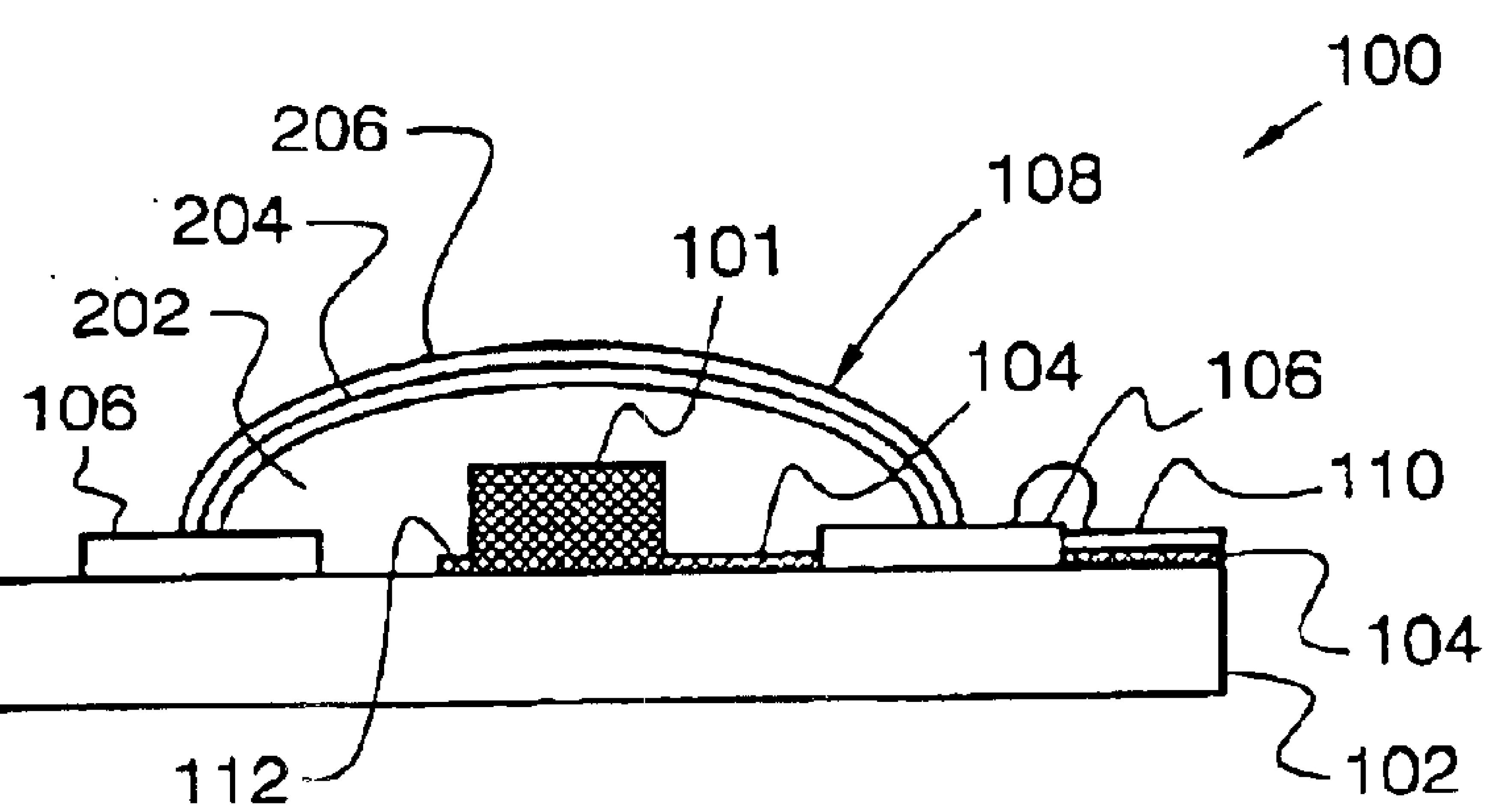
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Fig. 2

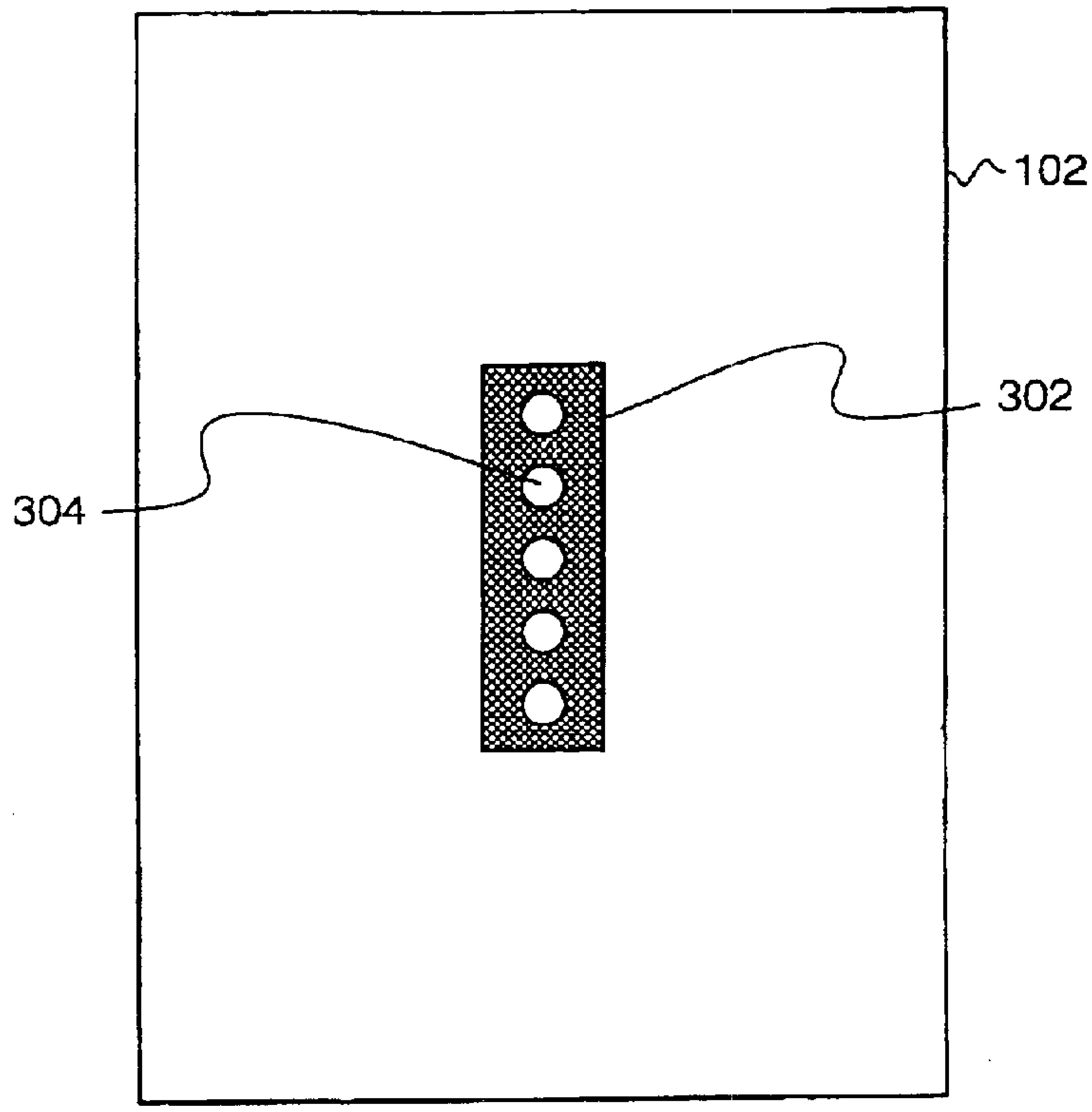


Fig.3

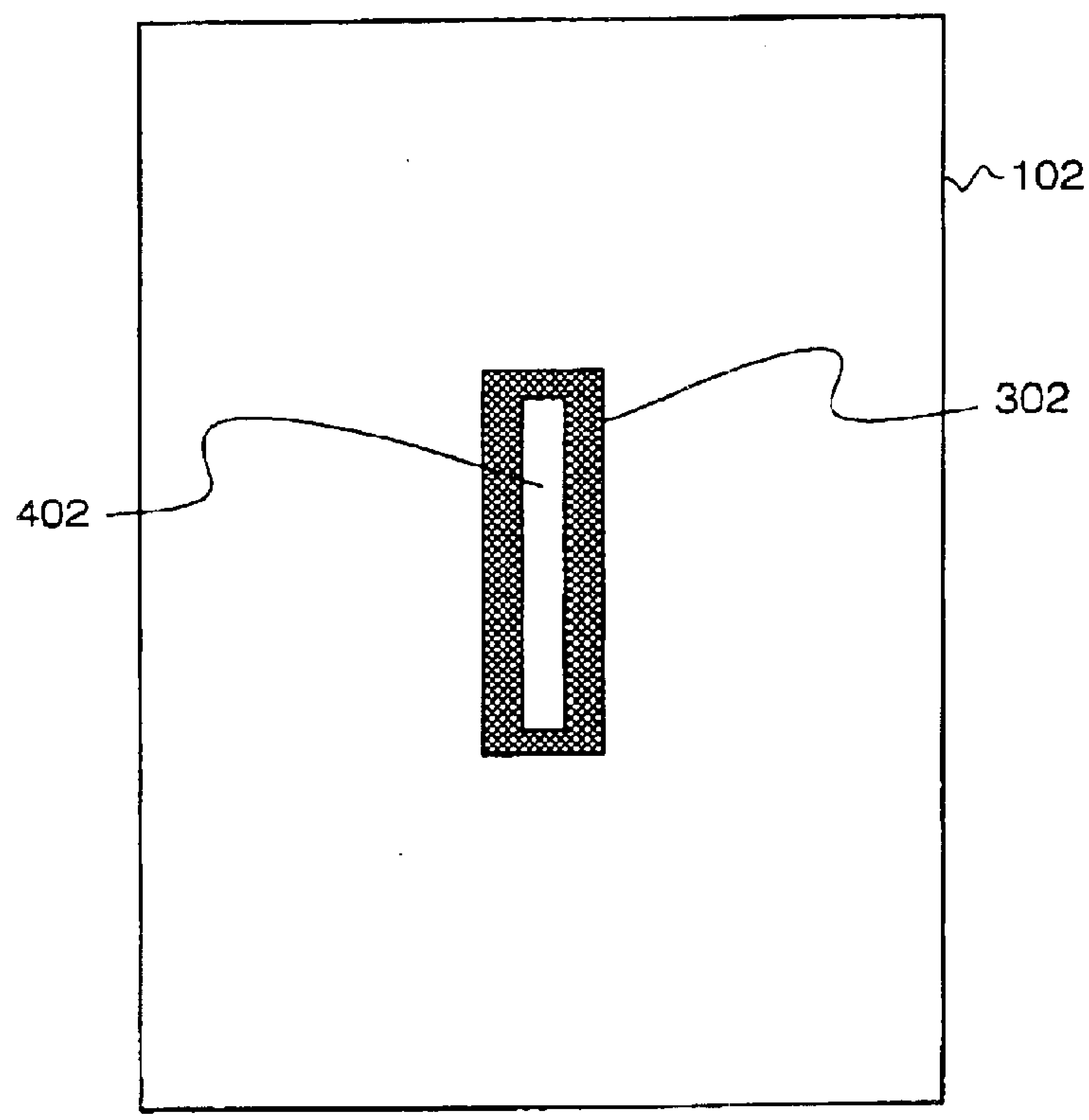
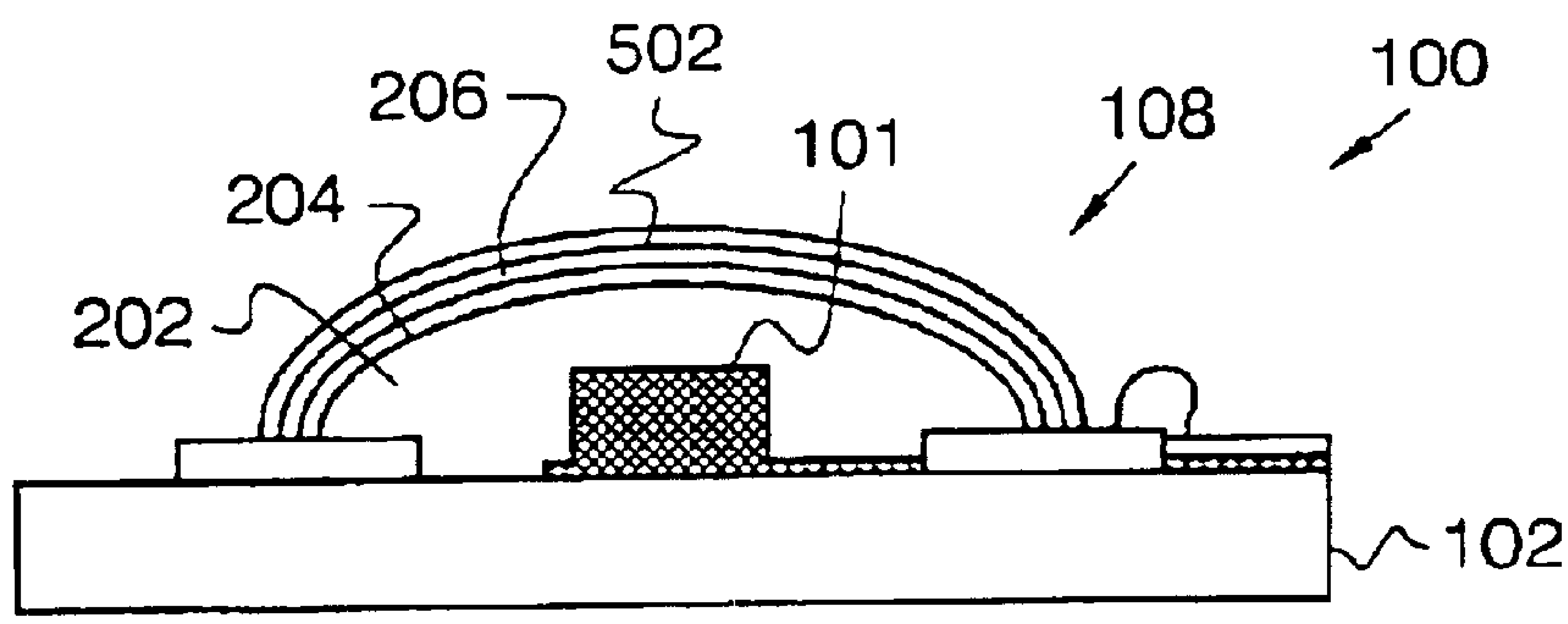


Fig.4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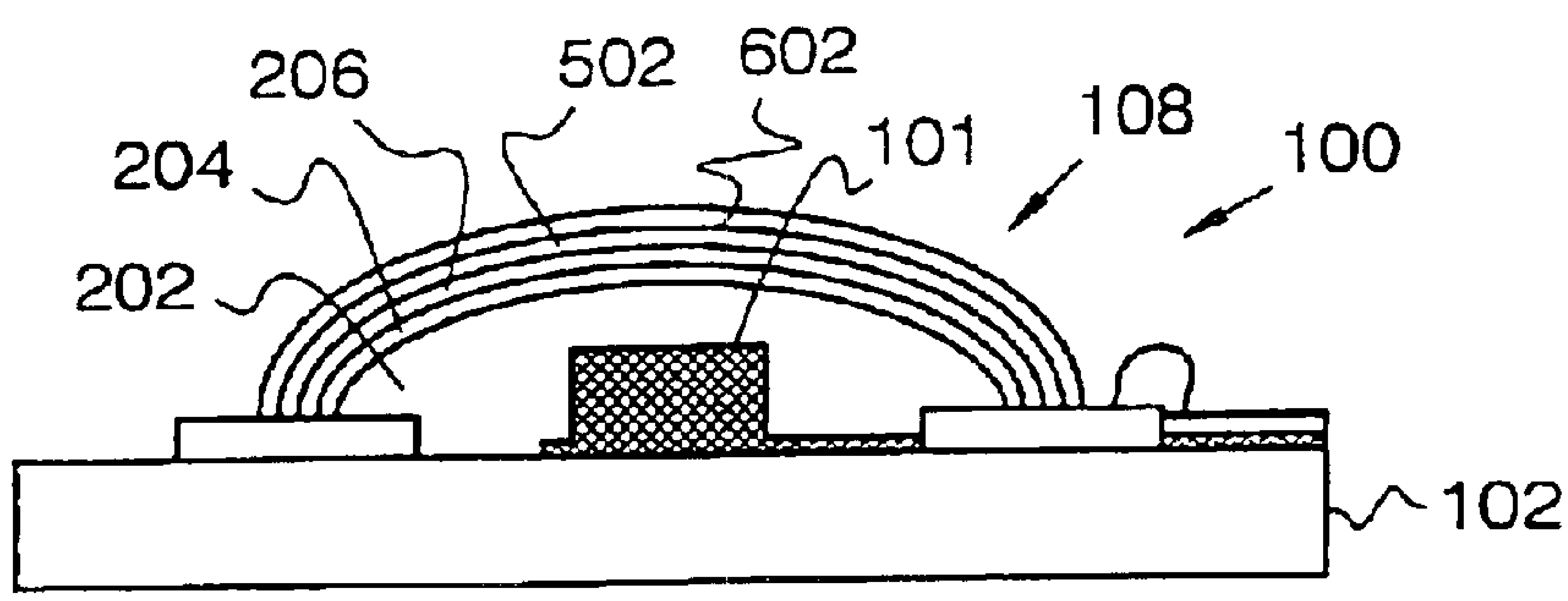
102

Fig. 5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202
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Fig. 6

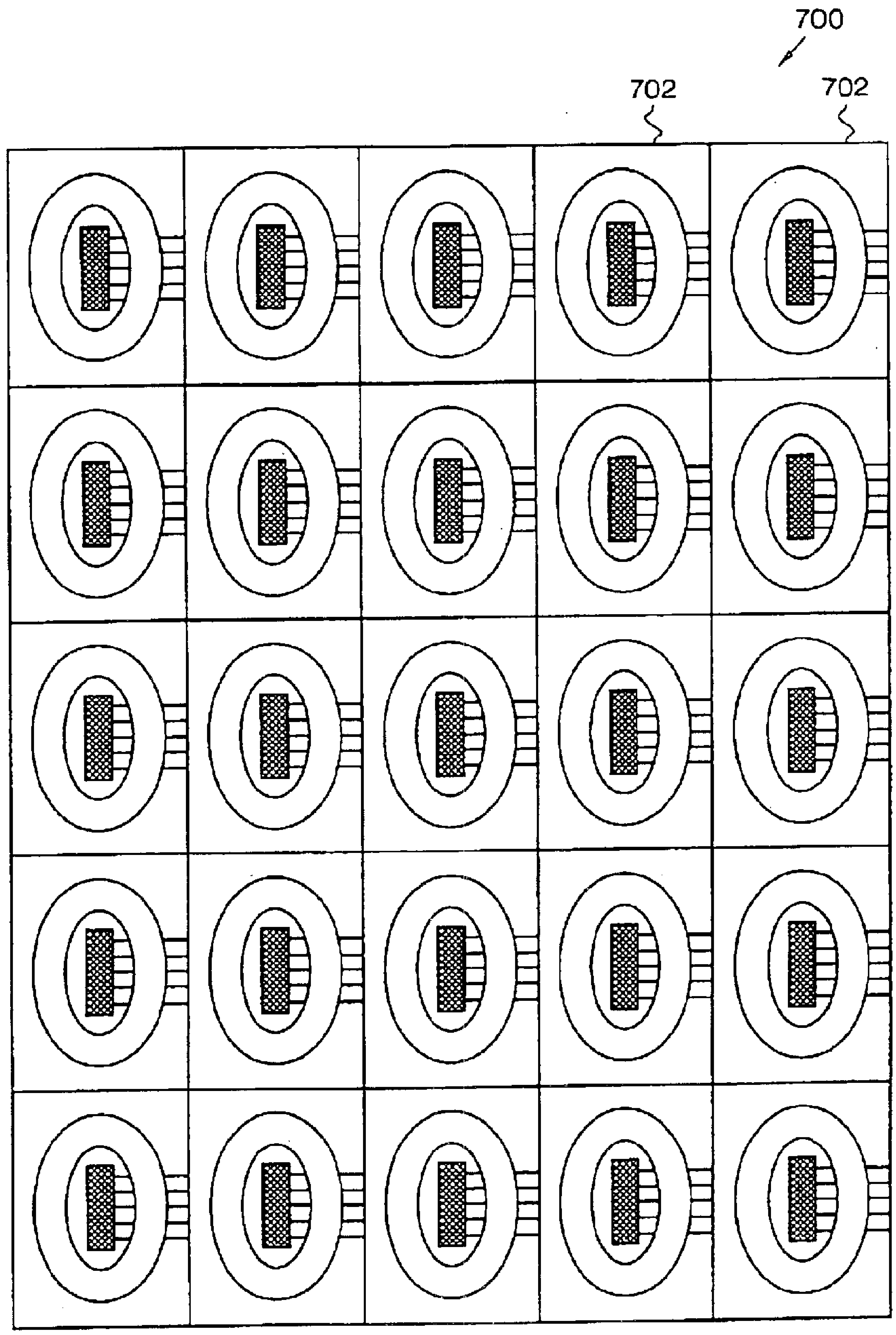


Fig. 7

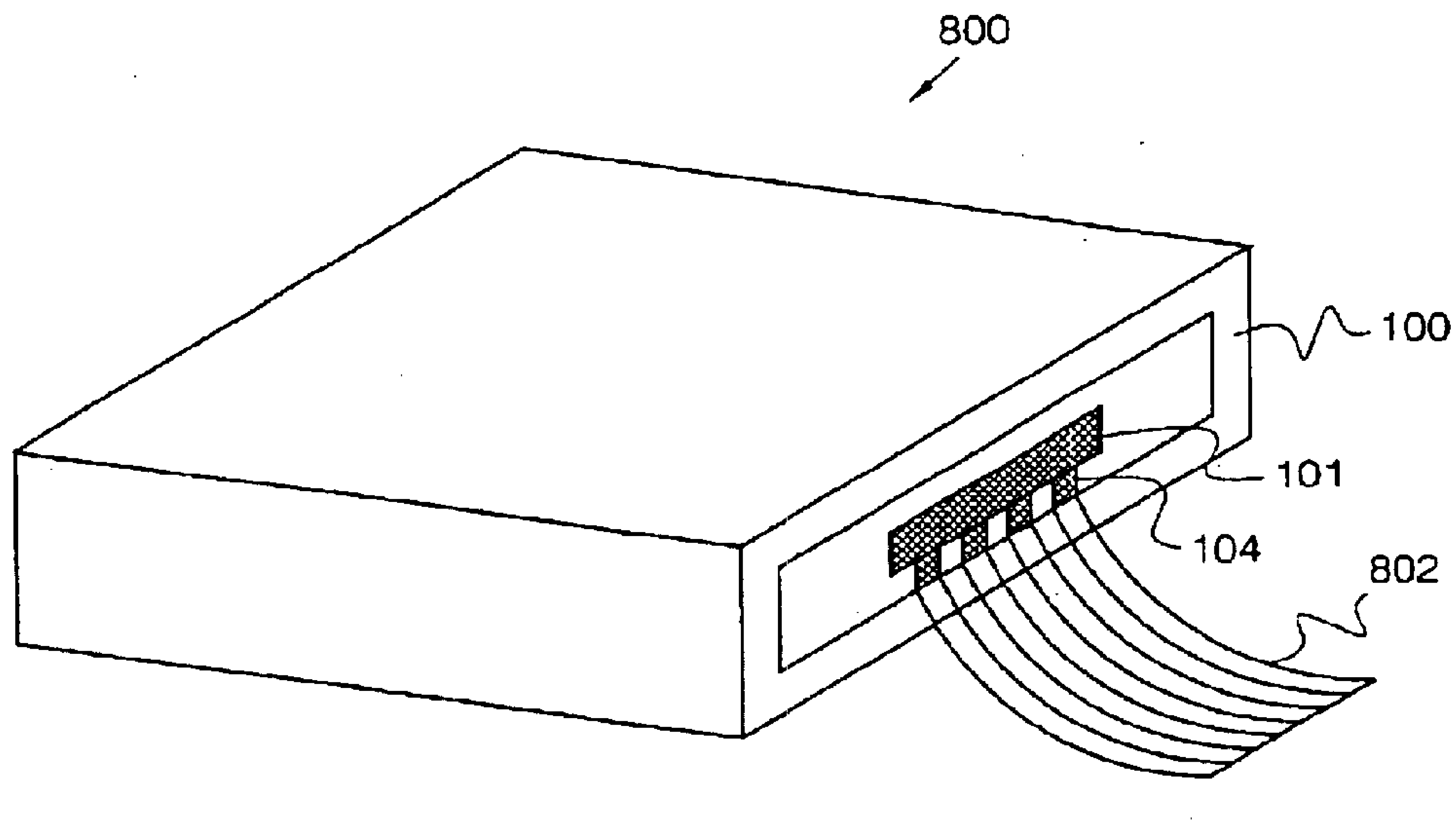


Fig. 8A

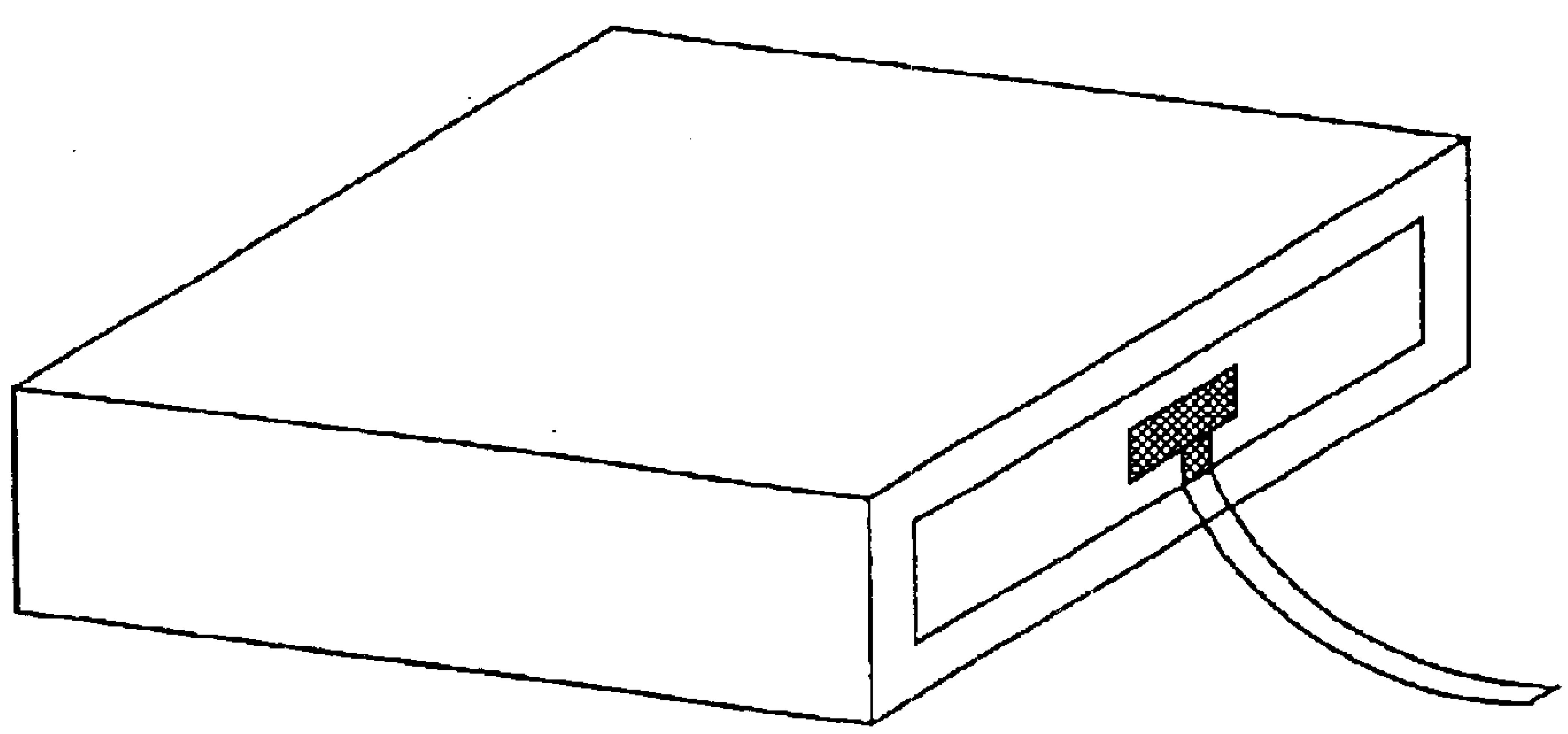
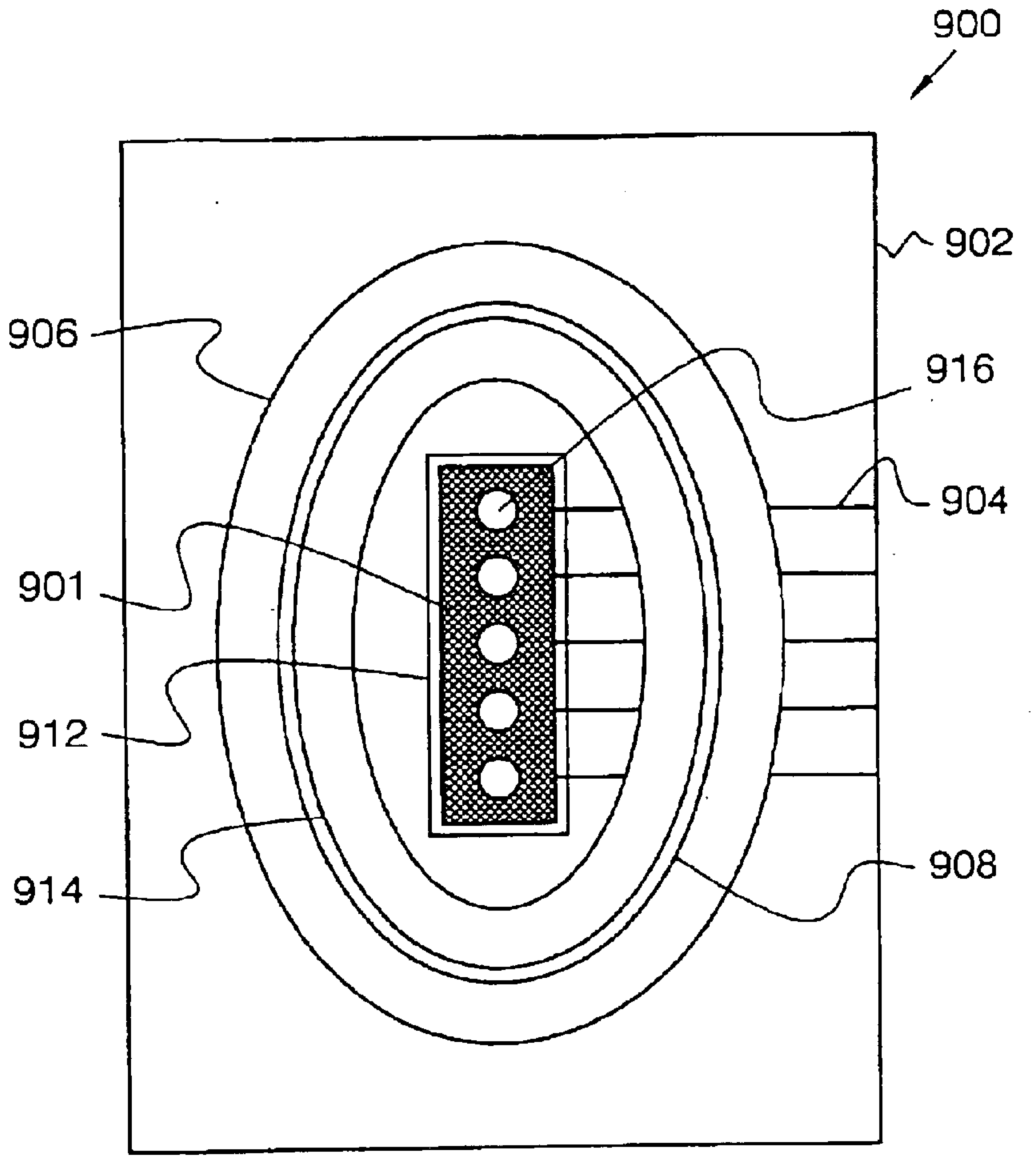


Fig. 8B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908

Fig. 9

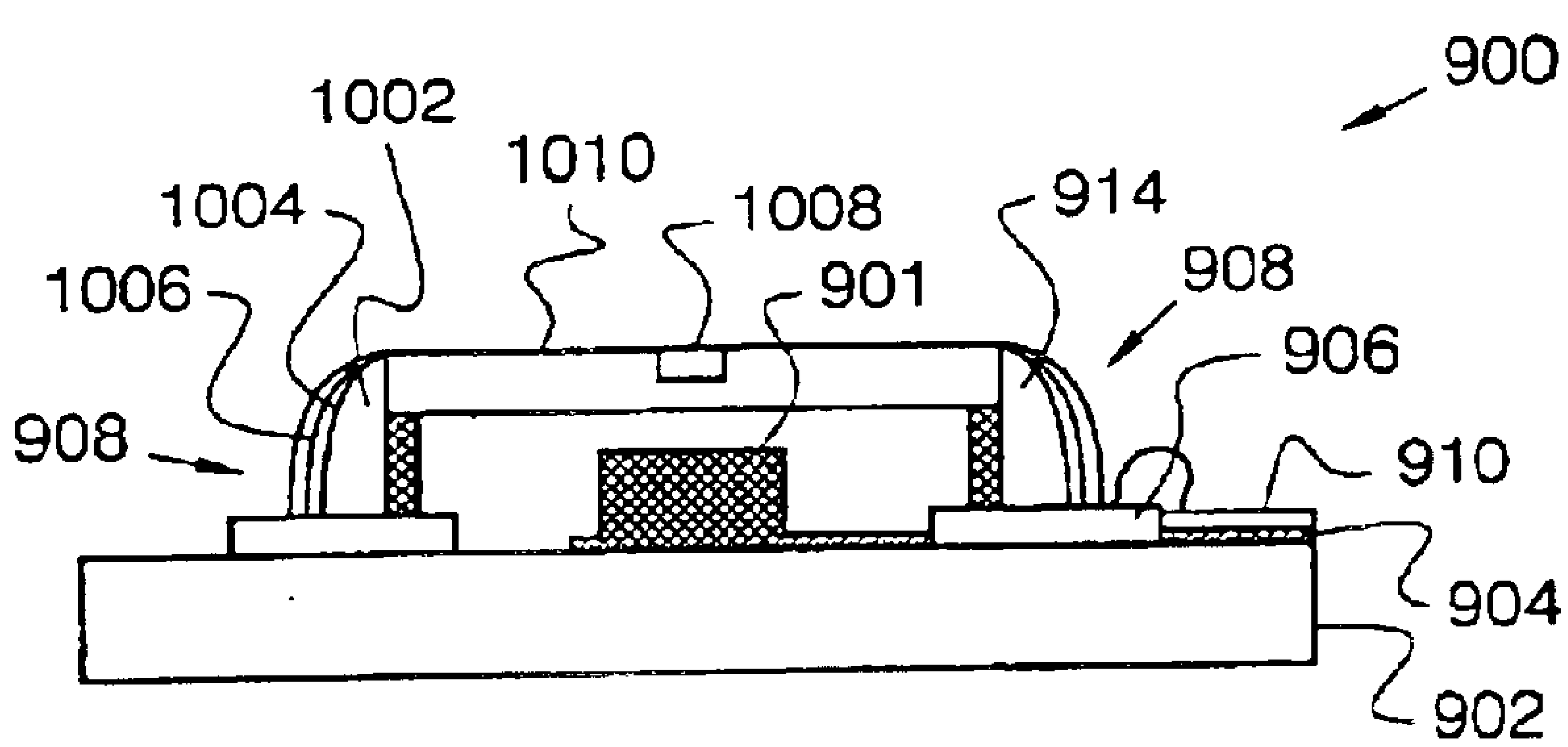
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Fig. 10

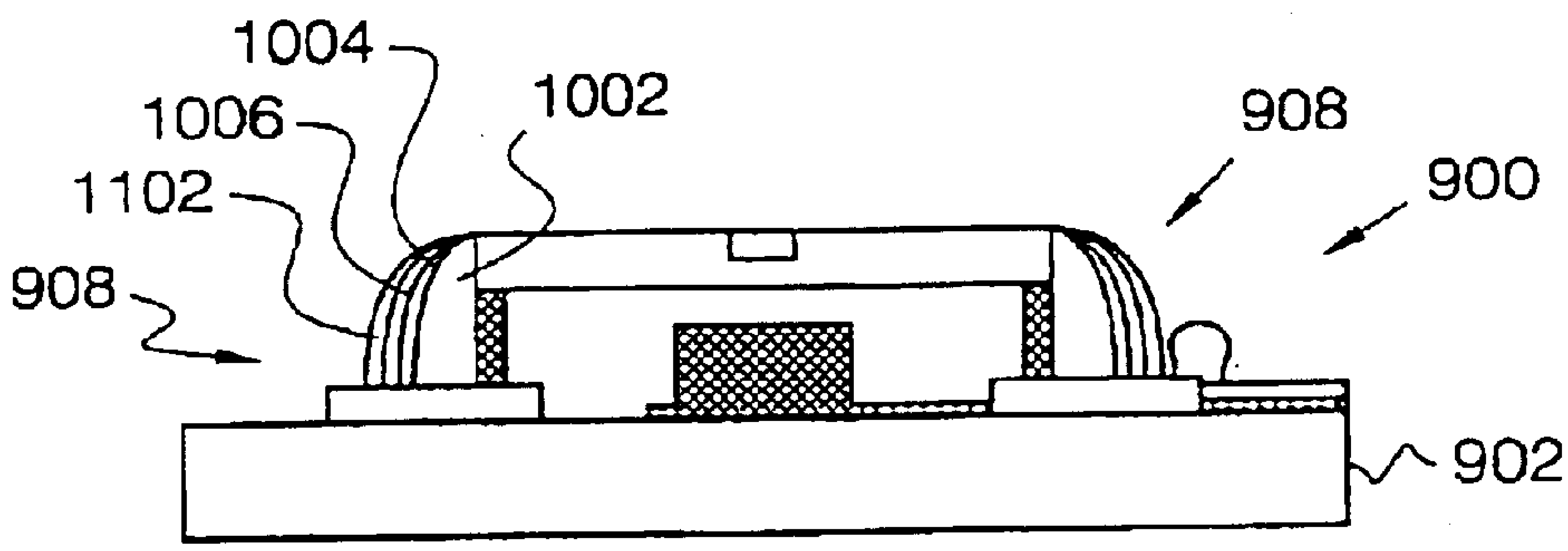
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Fig. 11

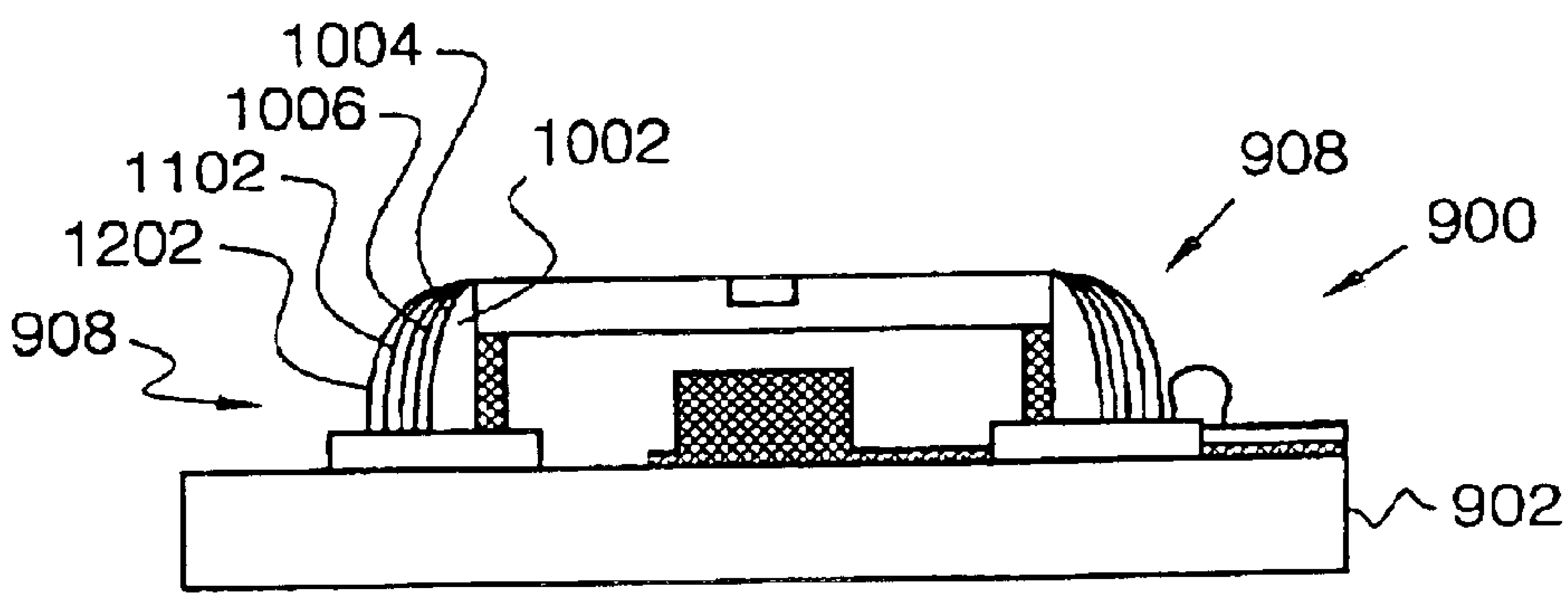
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Fig. 12

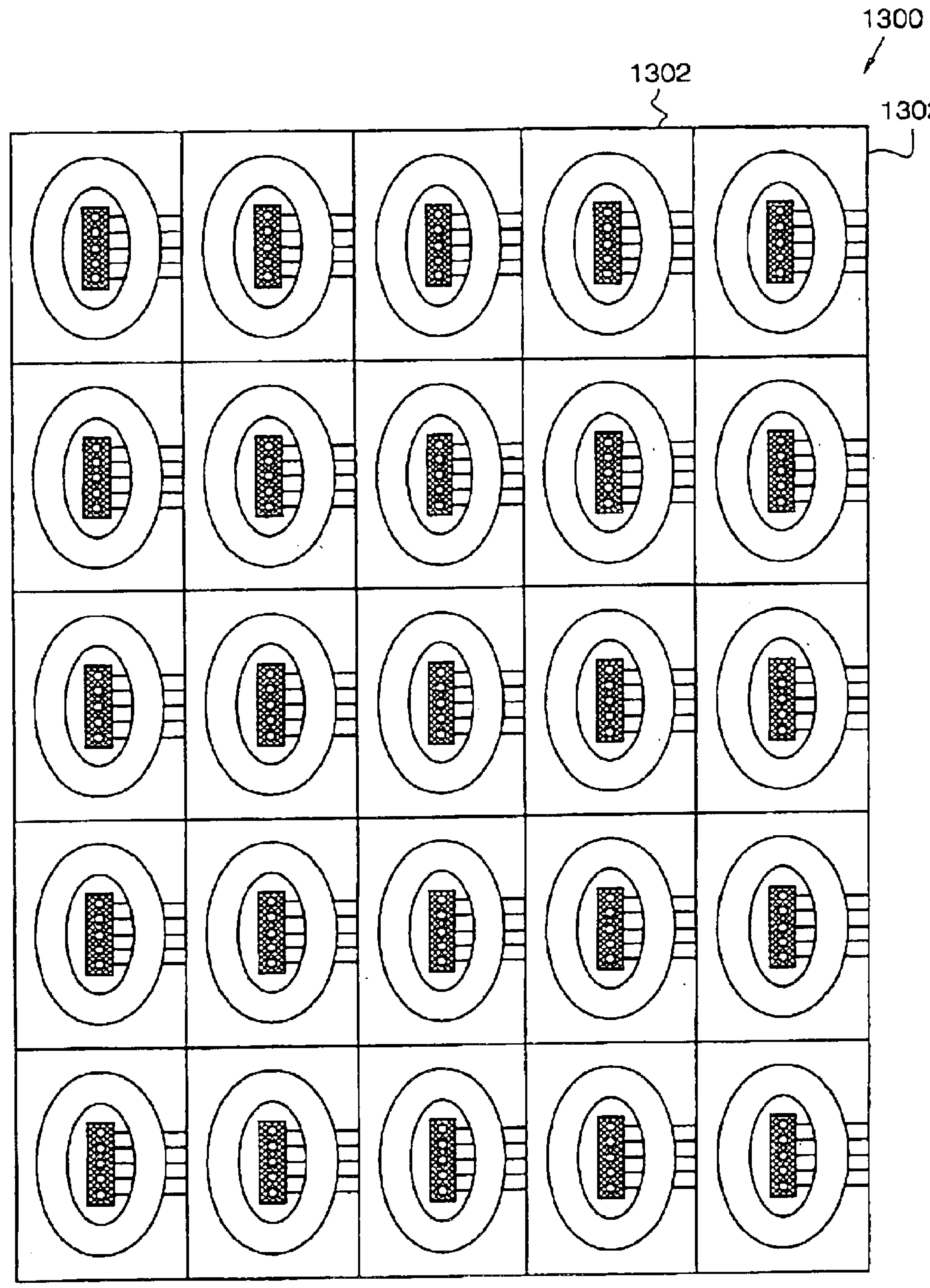

Fig. 13

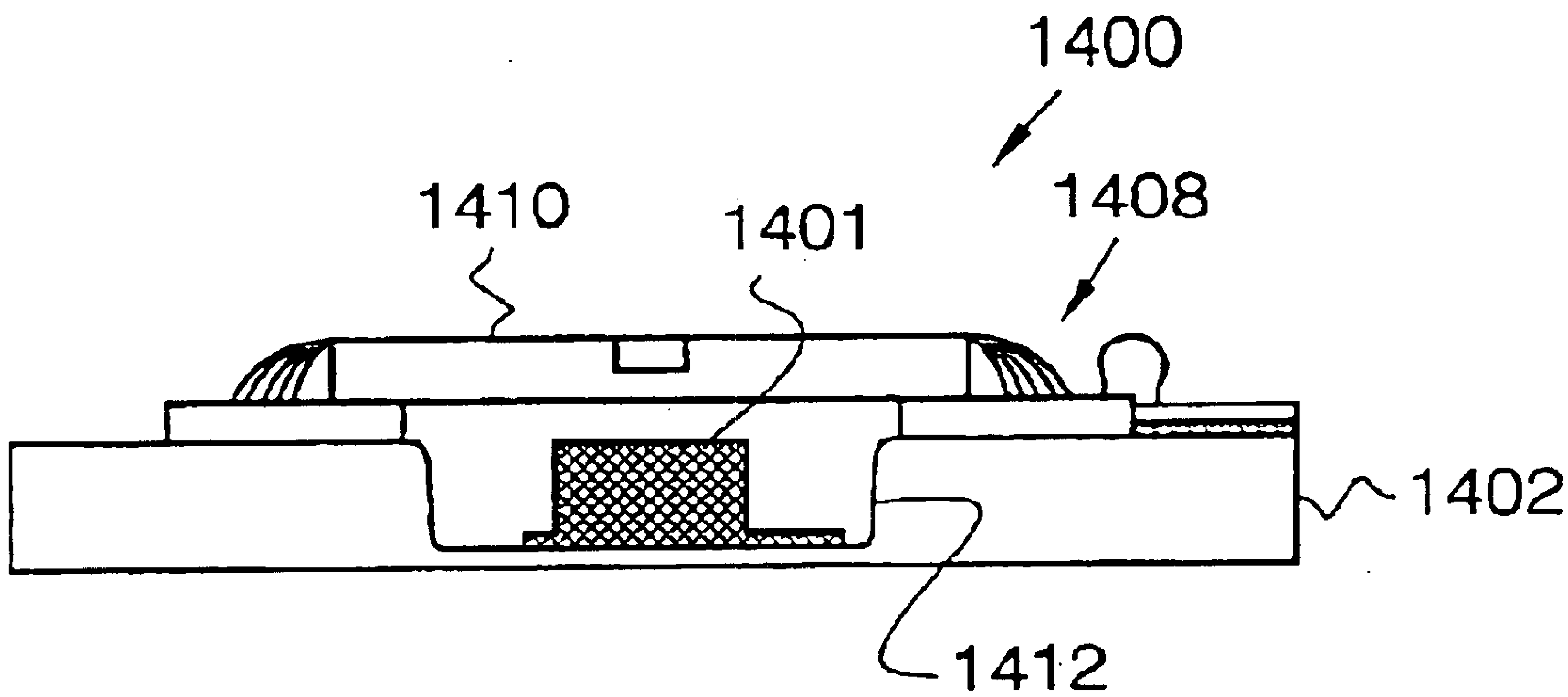

Fig. 14

METHOD AND APPARATUS FOR HERMETICALLY SEALING PHOTONIC DEVICES

BACKGROUND OF THE INVENTION

This application is a continuation of U.S. patent application Ser. No. 09/224,210, filed Dec. 30, 1998, now U.S. Pat. No. 6,588,949.

FIELD OF INVENTION

The present invention generally relates to methods and apparatus for hermetically sealing opto-electronic devices. More particularly, the present invention relates to a system for hermetically sealing photonic devices such as vertical cavity surface emitting lasers (VCSELs), photo-detectors, and the like.

DESCRIPTION OF RELATED ART

The use of photonic devices, such as VCSELs and photo-detectors, is becoming increasingly popular in the communications and electronics industry. Briefly, a VCSEL is a semiconductor laser which typically emits light normal to the surface to which it is mounted, and a photo-detector typically receives the light transmitted by the VCSEL. In general, photonic devices are used for transmitting data in the form of pulses of light in optical fibers such as in forming data links for parallel transmission and network computing. Photonic devices are particularly desirable as they can be processed, tested and screened on wafers, which facilitates high yield and thus low cost production.

However, the performance of photonic devices, has been found to be subject to environmental contaminants such as dust, moisture, and industrial chemicals. For example, moisture can damage or seriously degrade the performance of photonic devices. Therefore, it is desirable to hermetically seal photonic devices to protect them from dust, moisture, and other environmental contaminants.

A conventional method of sealing photonic devices involves covering the photonic devices in epoxy. As moisture can still penetrate the epoxy seal, however, a true hermetic seal is not formed. Other conventional methods of hermetically sealing photonic devices typically encase the photonic devices inside of TO can packages, which are typically Kovar metal cans with optical windows, and seals the packages with weld or solder. In generally, however, only one photonic device at a time can be hermetically sealed using these methods. Accordingly, these methods are generally costly and time intensive.

SUMMARY OF THE INVENTION

The present invention relates to hermetically sealing photonic devices such as vertical cavity surface emitting lasers (VCSELs), photo-detectors, and the like. In accordance with an exemplary embodiment of the present invention, a photonic device is mounted on a substrate material and sealed in a flexible hermetic seal. In one configuration, the photonic device is configured to emit or to receive light through the substrate material. In this configuration, the photonic device is covered with an adhesive layer and a metal layer deposited onto the adhesive layer. In another configuration, the photonic device is configured to emit or to receive light in a direction substantially vertically upward from the substrate material. In this configuration, a cover is placed over the photonic device, then the cover is hermetically sealed to the substrate material with an adhesive layer and a metal layer deposited onto the adhesive layer. In both configurations, the photonic devices are hermetically sealed according to various aspects of the present invention on the substrate material without using a separate package. Accordingly, any number of hermetically sealed photonic device submounts can be mass produced on wafers using the present invention.

DESCRIPTION OF THE DRAWINGS

The subject matter of the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, may best be understood by reference to the following description taken in conjunction with the claims and the accompanying drawing, in which like parts may be referred to by like numerals:

FIG. **1** is a top plan view of a photonic device submount hermetically sealed in accordance with various aspects of the present invention;

FIG. **2** is a side view of the photonic device submount shown in FIG. **1**;

FIG. **3** is a bottom view of the photonic device submount shown in FIG. **1**;

FIG. **4** is a bottom view of an alternative configuration of the photonic device submount shown in FIG. **1**;

FIG. **5** is a side view of another alternative configuration of the photonic device submount shown in FIG. **1**;

FIG. **6** is a side view of yet another alternative configuration of the photonic device submount shown in FIG. **1**;

FIG. **7** is a top plan view of a plurality of photonic device submounts formed on a wafer in accordance with various aspects of the present invention;

FIGS. **8**A and **8**B are orthogonal view of photonic device submounts mounted in ferrules in accordance with various aspects of the present invention.;

FIG. **9** is a top plan view of another photonic device submount flexibly and hermetically sealed in accordance with various aspects of the present invention;

FIG. **10** is a side view of the photonic device submount shown in FIG. **9**;

FIG. **11** is a side view of another configuration of the photonic device submount shown in FIG. **9**;

FIG. **12** is a side view of yet another configuration of the photonic device submount shown in FIG. **9**;

FIG. **13** is a top plan view of a plurality of photonic device submounts formed on a wafer in accordance with various aspects of the present invention; and

FIG. **14** is a side view of a photonic device submount hermetically sealed in accordance with various aspects of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EXEMPLARY EMBODIMENT

The subject matter of the present invention is particularly suited for use in connection with photonic devices, such as VCSELs, photo-detectors, and the like. As a result, exemplary embodiments of the present invention are described in that context. It should be recognized, however, that such description is not intended as a limitation on the use or applicability of the present invention, but is instead provided to enable a full and complete description of the exemplary embodiments.

A flexible hermetic sealing system according to various aspects of the present invention suitably provides for hermetically sealing photonic devices on a substrate material such as glass, silicon, ceramic, plastic, printed circuit board, and the like. For the sake of simplicity, the following description and related drawing figures describe and depict the sealing of a single photonic device submount according to various aspects of the present invention. As will be discussed in greater detail below, however, the present system can be used to seal any number of photonic device submounts on a wafer for mass production.

With reference to FIGS. **1** through **3**, in accordance with various aspects of the present invention, a photonic device submount **100** preferably includes a photonic device **101** suitably mounted to a substrate material **102** and suitably sealed in a hermetic seal **108**. In an exemplary embodiment, the photonic device **101** is preferably mounted such that the light emitters (not shown) or light receivers (not shown) of the photonic device **101** faces down to transmit or to receive light through the substrate material **102**. Accordingly, in the present exemplary embodiment, the substrate material **102** is preferably formed from a material transmissive to light such as glass, plastic, and the like.

With reference to FIG. **3**, a photo-resist layer **302** is suitably formed on the back side of the substrate material **102** with an alignment holes **304** for attaching optical fibers. Alternatively, with reference to FIG. **4**, the photo-resist layer **302** can be formed with an alignment slot **402** for attaching to an array of optical fibers. Additionally, although the photo-resist layer **302** is depicted for use with the photonic device **101** having a single line of light emitters or light receivers, the photo-resist layer **302** can be configured with rows of alignment holes **304** or alignment slots **402** for use with the photonic device **101** having any number of lines or arrays of light emitters or light receivers.

The photo resist layer **302** according to various aspects of the present invention facilitates passive alignment of optical fibers to the alignment holes **304** or alignment slot **402**. Accordingly, the photonic device **101** need not be activated to align the optical fibers to the light emitters or the light receivers of the photonic device **101**. In contrast, in active alignment, the photonic device **101** would need to be activated in order to determine the quality of the signal transmitted to or received from the optical fibers. Thus, passive alignment of optical fibers has the advantages of being less costly, less time consuming, and more conducive to mass production systems than active alignment.

With reference to FIGS. **1** and **2**, prior to the mounting of the photonic device **101** on the top side of the substrate material **102**, a bonding pad **112** is suitably formed on the substrate material **102** using any convenient method. Additionally, signal lines **104** are also suitably formed on the substrate material **102** using any convenient method. In the present exemplary embodiment, a conductive material, such as gold, silver, copper, titanium, chromium, and the like, is deposited to form the bonding pad **112** and the signal lines **104**.

As will be described in greater detail below, when the photonic device **101** is mounted on the bonding pad **112**, the photonic device **101** communicates with other components, other communication devices, and the like through the signal lines **104**. Therefore, it should be appreciated that the number and configuration of the signals lines **104** can vary depending on the particular application. For example, when the photonic device **101** is configured with one light emitter or receiver, only one or two signal lines may be used for connecting the photonic device **101** to other components, other communication devices, and the like. Additionally, although the signal lines **104** are depicted in the present exemplary embodiment as extending from only one side of the substrate material **102**, it should be recognized that any number of signal lines **104** can extend from any number of sides of the substrate material **102**.

After the signal lines **104** are formed, a dielectric layer **106** is then suitably formed around the area in which the photonic device **101** is to be mounted and over the signal lines **104**. With particular reference to FIG. **2**, the dielectric layer **106** electrically isolates the signal lines **104** from the flexible hermetic seal **108**. Accordingly, the dielectric layer **106** can be formed from any suitable nonconducting material using any convenient method. In the present exemplary embodiment, an additional layer of glass is deposited onto the substrate material **102** to suitably form the dielectric layer **106**. Although the dielectric layer **106** is depicted in FIG. **1** as surrounding the photonic device **101**, the dielectric layer **106** can be formed to cover the signal lines **104** without surrounding the photonic device **101**. Therefore, it should be appreciated that the shape and configuration of the dielectric layer **106** can vary depending on the particular application.

As will be described in greater detail below, the flexible hermetic seal **108** is formed according to various aspects of the present invention by depositing layers of metal onto an adhesive layer. Accordingly, a removable "lift-off" layer **110** is suitably formed in any areas which are to remain free of the deposited metal. After the flexible hermetic seal **108** is formed, the removable lift-off layer **110** can be peeled off to expose the protected areas. For example, in the present exemplary embodiment, the removable lift-off layer **110** is suitably formed over the portion of the signal lines **104** extending beyond the dielectric layer **106**. After the flexible hermetic seal **108** is formed, the removable lift-off layer **110** is peeled off and the exposed portion of the signal lines **104** can then be used for connecting to other components, other communication devices, and the like. Alternatively, the removable lift-off layer **110** can be formed over the entire surface of the substrate **102** and the dielectric layer **106**, then the areas which are to be covered by the flexible hermetic seal **108** can be etched away using any convenient method. In the present embodiment, the removable lift-off layer **110** can include photo-resist, tape, and the like.

The processing steps described thus far can be performed as a planar process; meaning that the above described processing steps can be performed on any number of photonic device submounts formed on a large substrate area such as on a wafer. Accordingly, with reference to FIG. **7**, a plurality of photonic device submounts **702** are formed in rows and columns on a wafer **700**. It should be appreciated that the order of processing of the bottom and the top of the wafer **700** can vary without deviating from the spirit and scope of the present invention. Accordingly, the top of the wafer **700** can be processed to suitably form the photonic device submounts **702**, then the bottom of the wafer **700** can be processed to suitably form the alignment holes **304** or the alignment slots **402** for each of the photonic device submounts **702** (FIGS. **3** and **4**).

With reference again to FIG. **2**, the photonic device **101** is suitably mounted on the bonding pad **112** using any convenient method. In the present exemplary embodiment, the photonic device **101** is preferably bonded to the bonding pad **112** using a flip-chip bonding process. With additional reference to FIGS. **3** and **4**, the light emitters or the light receivers of the photonic device **101** are suitably aligned with the alignment holes **304** or the alignment slot **402** formed in the bottom of the substrate **102**.

After the photonic device **101** is mounted on the substrate **102**, the hermetic seal **108** is suitably formed to seal the photonic device **101**. More particularly, an adhesive layer **202** is deposited to cover the photonic device **101**. In the present exemplary embodiment, the adhesive layer **202** is an optical grade moisture resistant adhesive such as a high temperature epoxy. The adhesive layer **202** is then cured using any suitable method. For example, the adhesive layer **202** can be placed into an oven to cure the adhesive layer **202**. It should be appreciated that the temperature and the exposure time required to cure the adhesive layer **202** depends largely on the particular adhesive used.

After the adhesive layer **202** is suitably cured, a metal layer **204** is then deposited on top of the adhesive layer **202** using any convenient method, such as e-beam deposition, thermal deposition, sputtering, and the like. The metal layer **204** adheres to the adhesive layer **202** to hermetically seal the photonic device **101**. In accordance with various aspects of the present invention, the metal layer **204** can include any metal or combination of metals such as chromium, gold, nickel, silver, titanium, and the like. Additionally, the metal layer **204** can also include metallic solder. In the present exemplary embodiment, the metal layer **204** is preferably chromium.

In one configuration of the present exemplary embodiment, a metal layer **206** is suitably deposited on top of the metal layer **204**. The metal layer **206** can be deposited using any convenient method, such as e-beam deposition, thermal deposition, sputtering, and the like. The metal layer **206** suitably adheres to the metal layer **204** to provide a stronger and more flexible hermetic seal. In the present exemplary embodiment, the metal layer **206** is preferably gold, however, it should be appreciated that the metal layer **204** and the metal layer **206** can include any metal or combination of metals for any particular application. Additionally, it should be appreciated that the metal layer **206** can be formed using any combination of methods. For example, when the metal layer **206** is gold, a relatively thin layer of gold can be formed using a deposition method. In an exemplary embodiment, a layer of approximately 2000 is preferably deposited. A thicker layer of gold can then be formed using an electroplating method to form a thicker layer of gold on top of the initial thin layer of gold. This method of combining a deposition method with an electroplating method has the advantage of reducing the cost of forming a thick layer of gold because an electroplating method is generally less costly than a deposition method, particularly for a precious metal such as gold.

With reference to FIG. **5**, in an alternative configuration of the present embodiment, a solder layer **502** according to various aspects of the present invention is suitably deposited on top of the metal layer **206** using any convenient method. For example, the solder layer **502** can be electroplated to the metal layer **206** then reflowed to mix with the metal layer **206**. In the present exemplary embodiment in which the metal layer **204** is chromium, the metal layer **206** includes two layers of metal; a layer of nickel on top of the layer of chromium (the metal layer **204**) and a layer of gold on top of the layer of nickel. Accordingly, when the solder layer **502** is reflowed, the solder layer **502** mixes with the layer of gold in the metal layer **206** and bonds with the layer of nickel in the metal layer **206**. In this manner, the size of the hermetic seal **108** can be increased without using additional quantities of gold, which can be costly.

With reference to FIG. **6**, in yet another alternative configuration of the present exemplary embodiment, a protective layer **602** according to various aspects of the present invention is suitably disposed on the solder layer **502** after reflowing the solder layer **502** to mix with the metal layer **206**. The protective layer **602** is preferably a conformable and flexible material, such as epoxy, polyamide, and the like, to protect the metal layer **204**, the metal layer **206**, and the solder layer **502** against scratching and cracking. It should be recognized that the protective layer **602** can be suitably applied to the metal layer **206** if only the metal layers **202** and **204** are to be used (FIG. **2**). Similarly, the protective layer **602** can be suitably applied to the metal layer **202** if only the metal layer **202** is to be used.

As described above, with reference again to FIGS. **1** and **2**, after the hermetic seal **108** has been suitably formed, the lift-off layer **110** is removed to expose the areas of the photonic device submount **100** which was protected from the metal deposition process used to form the heretics seal **108**. More particularly, with reference to FIG. **2**, the lift-off layer **110** is removed to expose the signal lines **104** for connecting to other components, other devices, and the like. Additionally, with reference to FIGS. **3** and **4**, optical fibers are suitably aligned and connected to the alignment holes **304** or the alignment slot **402** for connecting to other components, other devices, and the like.

With reference to FIG. **8**A, the photonic device submount **100** according to various aspects of the present invention is suitably configured within a ferrule **800**. More particularly, the photonic device submount **100** is suitably mounted to one end of the ferrule **800** such that the signal lines **104** can be suitably connected to other components through wires **802**. Accordingly, the optical fibers are connected to the bottom side of the photonic device submount **100** which is oriented into the ferrule **800** as depicted in FIG. **8**. It should be appreciated that the ferrule **800** can include any convenient ferrule such as an MT ferrule. Additionally, although the photonic device submount **100** is depicted in FIG. **8** as being connected to an array of wires **802**, it should be appreciated that the photonic device submount **100** can be connected to any number of wires **802**. For example, with reference to FIG. **8**B, the photonic device submount **100** is connected to a single wire **804**.

With reference to FIG. **7**, as described above, a plurality of photonic device submounts **702** can be formed on the wafer **700**. In this regard, the steps described above for mounting and hermetically sealing the photonic device **101** on the substrate **102** (FIGS. **1** and **2**) can be repeated for each photonic device submounts **702** on the wafer **700**. The photonic device submounts **702** are then separated using any convenient method such as scribing, sawing, and the like. In this manner, hermetically sealed photonic device submounts can be suitably mass produced.

The flexible hermetic sealing process according to various aspects of the present invention has thus far been described in conjunction with the photonic device submount **100** which is particularly suited for emitting or receiving light through the substrate **102** (FIGS. **1** and **2**). However, it should be recognized that the present invention can be used in conjunction with any type of photonic device submount configuration depending on the particular application. For example, the ensuing description and related drawings relate to a free space photonic device submount which emits or receives light through lenses rather than directly into optical fibers. Additionally, for the sake of simplicity, the ensuing description refers to a photonic device configured with light emitters to transmit light, for example, when the photonic device is a VCSEL. However, it should be recognized that the photonic device described below can also be configured with light receivers, for example when the photonic device is a photo-detector.

With reference to FIGS. **9** and **10**, in accordance with various aspects of the present invention, a photonic device submount **900** preferably includes a photonic device **901** suitably mounted to a substrate material **902** and suitably sealed in a flexible hermetic seal **908**. As described above, in this exemplary embodiment, the photonic device **901** is preferably mounted such that light emitters **916** of the photonic device **901** faces substantially vertically upward from the substrate material **102**. Accordingly, the substrate material **102** can include any suitable rigid material which is non-transmissive to light such as opaque ceramic, silicon, and the like. However, it should be recognized that the substrate material **102** can also include material which is transmissive to light such as glass, clear plastic, and the like. Additionally, although the photonic device **901** is depicted as having a single row of light emitters **916**, it should be recognized that the photonic device **901** can include any number of rows or arrays of light emitters without deviating from the spirit and scope of the present invention.

Similar to the prior exemplary embodiment described above, a bonding pad **901** and signal lines **904** are suitably formed on the substrate material **902** using any convenient method such as deposition, screen printing, and the like. Although in the present exemplary embodiment the signal lines **904** are depicted extending from only side of the substrate material **902**, any number of signal lines **904** may extend from any number of sides of the substrate material **902**.

Again, similar to the prior exemplary embodiment, after the signal lines **904** are formed on the substrate material **902**, a dielectric layer **906** is suitably formed around the area in which the photonic device **901** is to be mounted and over the signal lines **904**. With particular reference to FIG. **10**, the dielectric layer **906** electrically isolates the signal lines **904** from the flexible hermetic seal **908**. Accordingly, the dielectric layer **906** can be formed from any suitable nonconducting material using any convenient method. Although the dielectric layer **106** is depicted in FIG. **9** as surrounding the photonic device **901**, the dielectric layer **906** can be formed to cover the signal lines **904** without surrounding the photonic device **901**. Therefore, it should appreciated that the shape and configuration of the dielectric layer **906** can vary depending on the particular application.

As will be described in greater detail below, the flexible hermetic seal **908** is formed according to various aspects of the present invention by depositing layers of metal onto an adhesive layer. Accordingly, a removable lift-off layer **910** is suitably formed in any areas which are to remain free of the deposited metal. After the flexible hermetic seal **908** is formed, the removable lift-off layer **910** can be peeled off to expose the protected areas. For example, in the present exemplary embodiment, the removable lift-off layer **910** is suitably formed over the portion of the signal lines **904** extending beyond the dielectric layer **906**. After the flexible hermetic seal **908** is formed, the removable lift-off layer **910** is peeled off and the exposed portion of the signal lines **904** can then be used for connected to other components, other communication devices, and the like. Alternatively, the removable lift-off layer **910** can be formed over the entire surface of the substrate **902** and the dielectric layer **906**, then the areas which are to be covered by the flexible hermetic seal **908** can be etched away using any convenient method. In the present embodiment, the removable lift-off layer **910** includes photo-resist, tape, and the like.

Similar to the prior exemplary embodiment, the processing steps described thus far can be performed as a planar process; meaning that the above described processing steps can be performed on any number of photonic device submounts formed on a large substrate area such as a wafer. Accordingly, with reference to FIG. **13**, a plurality of photonic device submounts **1302** are formed in rows and columns on a wafer **1300**.

With reference again to FIGS. **9** and **10**, the photonic device **901** is suitably mounted on the bonding pad **912** using any convenient method such as a flip-chip bonding process. A spacer **914** is then suitably disposed to support a cover **1010** over the photonic device **901**. Additionally, the spacer **914** according to various aspects of the present invention suitably provides for a gap between the photonic device **901** and the cover **1010**. Accordingly, the amount of the gap formed between the photonic device **901** and the cover **1010** can be adjusted by adjusting the height of the spacer **914**. It should be recognized that the appropriate amount of gap between the photonic device **901** and the cover **1010** depends largely on the particular application. The spacer **914** can be formed from any suitable rigid material and formed in any size and configuration to support the cover **1010**. Additionally, the spacer **914** is preferably formed from a material with a small thermal expansion characteristic or a thermal expansion characteristic similar to the substrate material **901**, such as ceramic, glass, and the like.

The cover **1010** includes lenses **1008** through which light can be emitted from the photonic device **901**. Accordingly, the lenses **1008** are formed on the cover **1010** to align with the light emitters **916** of the photonic device **901**. The lenses **1008** can include any convenient lenses, such as digital lenses, holographic lenses, and the like, and can be formed from any material transmissive to light. Additionally, the cover **1010** may also be formed from a material transmissive to light, in which case the lenses **1008** can be etched onto the cover **1010**. Alternatively, the cover **1010** can be formed from a material non-transmissive to light, in which case the lenses **1008** are suitably fixed into the cover **1010**.

It should be appreciated that the cover **1010** and the spacer **914** can be configured as a single unit such as a cap. Additionally, a positioning guide (not shown), such as a pin, a ring, and the like, can be disposed on the dielectric layer **906** to assist in positioning the spacer **914** on the dielectric layer **906**. Alternatively, with reference to FIG. **14**, a photonic device submount **1400** can be configured with a substrate **1402** formed with a recess **1414**. Accordingly, a flat cover **1410** can be sealed with hermetic seal **1408** over a photonic device **1401** without using a spacer.

With reference again to FIGS. **9** and **10**, after the cover **1010** is placed over the photonic device **901**, the cover **1010** is suitably covered with a lift-off layer to protect the cover **1010**, then the flexible hermetic seal **908** is suitably formed to seal the photonic device **901** and to hold the cover **1010** in place over the photonic device **901**. More particularly, an adhesive layer **1002** is deposited adjacent to the spacer **914** and the edges of the cover **1010**. As the adhesive layer **1002** remains flexible until it is cured, the cover **1010** can be adjusted to ensure that the lenses **1008** are aligned with the light emitters **916** on the photonic device **901**. In the present embodiment, the adhesive layer **1002** is an optical grade moisture resistant adhesive such as a high temperature epoxy. The adhesive layer **1002** is then cured using any convenient method. For example, the adhesive layer **1002** can be placed into an oven to cure the adhesive layer **1002**. It should be appreciated that the oven temperature and the exposure time required to cure the adhesive layer **1002** depends largely on the particular adhesive used.

After the adhesive layer **1002** is cured, a metal layer **1004** is then deposited on top of the adhesive layer **1002** using any convenient method, such as e-beam deposition, thermal deposition, sputtering, and the like. The metal layer **1004** adheres to the adhesive layer **1002** to hermetically seal the photonic device **901**. The metal layer **1004** can include any metal or combination of metals such as chromium, gold, nickel, silver, titanium, and the like. Additionally, the metal layer **1004** can also include metallic solder. In the present exemplary embodiment, the metal layer **1004** is preferably chromium.

In one configuration of the present exemplary embodiment, a metal layer **1006** is then suitably deposited on top of the metal layer **1004**. The metal layer **1006** can be deposited using any convenient method, such as e-beam deposition, thermal deposition, sputtering, and the like. The metal layer **1006** suitably adheres to the metal layer **1004** to provide a stronger and more flexible hermetic seal. In the present exemplary embodiment, the metal layer **1006** is preferably gold, however, it should be appreciated that the metal layer **1004** and the metal layer **1006** can include any metal or combination of metals for any particular application. Additionally, it should be appreciated that the metal layer **1006** can be formed using any combination of methods. For example, when the metal layer **1006** is gold, a relatively thin layer of gold can be formed using a deposition method. In an exemplary embodiment, a layer of approximately 2000 is preferably deposited. A thicker layer of gold can then be formed using an electroplating method to form the thicker layer of gold on top of the initial thin layer of gold. This method of combining a deposition method with an electroplating method has the advantage of reducing the cost of forming a thick layer of gold because an electroplating method is generally less costly than a deposition method, particularly for a precious metal such as gold.

With reference to FIG. **11**, in an alternative configuration of the present exemplary embodiment, a solder layer **1102** is suitably deposited on top of the layer **1006** using any convenient method. For example, the solder layer **1102** can be electroplated to the metal layer **1006** then reflowed to mix with the metal layer **1006**. In the present exemplary embodiment in which the metal layer **1004** is chromium, the metal layer **206** includes two layers of metal; a layer of nickel on top of the layer of chromium (the metal layer **1004**) and a layer of gold on top of the layer of nickel. When the solder layer **1102** is reflowed, the solder layer **1102** mixes with the layer of gold in the metal layer **1006** and bonds with the layer of nickel in the metal layer **1006**. In this manner, the size of the hermetic seal **908** can be increased without using additional quantities of gold, which is costly.

With reference to FIG. **12**, in yet another alternative configuration of the present exemplary embodiment, a protective layer **1202** is suitably disposed on the solder layer **1102** after reflowing the solder layer **1002** to mix with the metal layer **1006**. The protective layer **1202** is preferably a conformable and flexible material, such as epoxy, polyamide, and the like, to protect the metal layer **1004**, the metal layer **1006**, and the solder layer **1102** against scratching and cracking due to temperature variations. It should be recognized that the protective layer **1202** can be applied to the metal layer **1006** if only the metal layers **1002** and **1004** are to be used (FIG. **10**). Similarly, the protectively layer **1202** can be applied to the metal layer **1002** if only the metal layer **1002** is to be used.

As described above, with reference again to FIGS. **9** and **10**, after the hermetic seal **908** has been suitably formed, the lift-off layer **910** is removed to expose the areas of the photonic device submount **900** which was protected from the metal deposition process used to form the hermetic seal **908**. More particularly, with reference to FIG. **10**, the lift-off layer **910** is removed to expose the signal lines **904** for connecting to other components, other devices, and the like. Additionally, the lift-off layer which was placed on top of the cover **1010** is also removed.

With reference to FIG. **13**, as described above, the plurality of photonic device submounts **1302** can be formed on the wafer **1300**. In this regard, the steps described above for mounting and hermetically sealing the photonic device **901** on the substrate **902** (FIGS. **9** and **10**) can be repeated for each photonic device submounts **1302** on the wafer **1300**. The photonic device submounts **1302** are then separated using any convenient method such as scribing, sawing, and the like. In this manner, hermetically sealed photonic device submounts can be suitably mass produced.

Although the present invention has been described in conjunction with particular embodiments illustrated in the appended drawing figures, various modifications may be made without departing from the spirit and scope of the invention. Therefore, the present invention should not be construed as limited to the specific form shown in the drawings and described above.

What is claimed:

1. A method of sealing a photonic device on a substrate, the method comprising the steps of:

surrounding an area of the substrate around the photonic device with a dielectric layer;

encapsulating the area with an adhesive; and

forming a metallic layer on the adhesive to thereby form a hermetic seal around the photonic device.

2. The method of claim **1** further comprising the step of forming a photoresist layer on a side of the substrate opposite the photonic device.

3. The method of claim **2** further comprising the step of forming a hole through the photoresist layer extending through at least a portion of the substrate.

4. The method of claim **3** wherein the hole is configured to receive an optical fiber and to align the optical fiber to the photonic device.

5. The method of claim **1** further comprising the steps of forming a bonding pad for the photonic device and at least one signal line on the substrate, and wherein the encompassing step comprises forming the dielectric layer over the at least one signal line.

6. The method of claim **5** further comprising the steps of placing a lift-off layer on the at least one signal layer prior to the encapsulating step.

7. The method of claim **6** further comprising the step of removing the lift-off layer after the encapsulating step.

8. A method of sealing a photonic device on a substrate, the method comprising the steps of:

forming a bonding pad and at least one signal lead on the substrate;

placing a lift-off layer on at least a portion of the at least one signal lead;

surrounding an area of the substrate with a dielectric layer placed on top of the at least one signal lead;

placing the photonic device within the area surrounded by the dielectric layer;

encapsulating the area with an adhesive;

forming a metallic layer on the adhesive to thereby form a hermetic seal around the photonic device; and

removing the lift off layer after the metallic layer is formed to expose the portion of at least one signal lead.

9. The method of claim **8** further comprising the steps of forming a photoresist layer on a back surface of the substrate opposite the bonding pad, wherein the photoresist layer has at least one hole extending into the substrate for receiving an optical fiber.

10. The method of claim **9** further comprising the step of aligning the hole with the photonic device.

11. A method of sealing a photonic device on a substrate, the method comprising the steps of:

mounting the photonic device to the substrate;

positioning a cover having an edge over the photonic device; and

providing an adhesive around the edge of the cover to thereby encapsulate the photonic device;

forming a metallic layer on the adhesive to create a hermetic seal around the photonic device.

12. The method of claim **11** further comprising the steps of supporting the cover above the substrate with at least one spacer.

13. The method of claim **12** further comprising the step of forming the metallic layer with solder.

14. The method of claim **11** further comprising the step of providing the cover in the form of an optically transmissive window.

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